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Effect of Immersion in Disinfectants on Cyclic Fatigue Resistance of Nickel-Titanium Instruments: An in Vitro Study

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ABSTRACT

Objectives: The current study aimed to assess the cyclic fatigue resistance of two nickel-titanium (NiTi) rotary files after immersion in 5% sodium hypochlorite (NaOCl) and Deconex.

Materials and Methods: In this in vitro study, 90 new M3 Pro Gold size 25.06 and size F2 SP1 files were tested. Forty-five files of the same brand were randomly distributed into three groups (n=15) and submitted to the following immersion protocol for 5 minutes at room temperature: no immersion (control group), immersion in 5% NaOCl, and immersion in Deconex. The cyclic fatigue resistance of the files was then measured in a custom-made tester. Two-way ANOVA was applied to compare the cyclic fatigue resistance of SP1 and M3 NiTi rotary files based on the type of disinfectant solution. Post-hoc LSD test was used for pairwise comparisons and $P<0.05$ was considered significant.

Results: Two-way ANOVA indicated a significant difference in the mean cyclic fatigue resistance of M3 and SP1 NiTi rotary files. The M3 files immersed in NaOCL displayed the lowest and the SP1 files immersed in Deconex showed the maximum cyclic fatigue resistance. The effect of type of disinfectant solution ($P<0.001$) and type of NiTi file ($P<0.001$) on cyclic fatigue resistance was statistically significant.

Conclusions: The cyclic fatigue resistance of NiTi rotary instruments can be affected by immersion in disinfectants, and the specific type of file and disinfectant used will ultimately determine the extent of this impact.

Keywords: Dental Disinfectants; Dental Instruments; Root Canal Preparation; Sodium Hypochlorite; Nitinol

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INTRODUCTION

The aim of root canal treatment is to disinfect the root canals through their chemomechanical instrumentation and obturation to inhibit canal reinfection [1,2]. Use of nickel-titanium (NiTi) rotary files has become progressively widespread amongst endodontists over the past three decades [3]. The manufacturers recommend discarding the NiTi files after a certain number of utilization or earlier if any apparent deformation is observed [4].

Different countries have distinct guidelines for reuse of NiTi files. Reuse of NiTi files is not recommended in the United Kingdom, while the Australian Endodontic Society has suggested using the files for 10-11 times. The American Association of Endodontics has not made any specific recommendations in this respect [5,6]. In underdeveloped and developing countries, file disposal after one single use imposes a huge financial burden on patients; therefore, sterilization of files in order to reuse them appears to be a more practical solution. On the other hand, cross infection is a high-priority concern in dentistry, particularly in endodontics, as instruments, and mainly endodontic files, are in direct contact with infective agents, blood, and saliva [4].

To date, no specific protocol has been proposed to sterilize NiTi files. A number of studies have argued that brushing the files, then immersing them in chemical disinfectants, followed by ultrasonic cleaning and eventual autoclaving of the files would be the most efficient protocol to sterilize the files [7]. Scrubbing of the files before sterilization eliminates organic debris and inhibits the proliferation of pathogens, which in turn diminishes the risk of cross-contamination [4]. In dental practice, quite a few methods are applied to clean the files before sterilization, although none of the approaches are measured as a standard cleaning protocol [8]. One of the most prevalent and effective procedures to clean the files is to immerse the files in chemical disinfectants such as Deconex and sodium hypochlorite (NaOCl). Some studies have demonstrated that immersion of NiTi files in chemical disinfectants causes alterations in cyclic fatigue resistance of the files. Cyclic fatigue refers to the number of rotational cycles that a file can withstand before fracture.

Fracture of rotary instruments may be due to torsion or flexural cyclic fatigue [9-11]. Torsional fracture occurs when an instrument tip or another part of the instrument is locked in the canal while the shank continues to rotate [12]. Fracture caused by fatigue through flexure occurs because of metal fatigue. The instrument is not locked in the canal, but it rotates with no restriction at the curvature, creating tension/ compression cycles at the point of maximum flexure until fracture occurs. This recurring tension- compression cycle, caused by rotation within curved canals, causes cyclic fatigue of the instrument over time and might be an important parameter in instrument fracture [3,13]. The importance of cyclic fatigue resistance in performance of NiTi rotary files and the impact of immersion in chemical disinfectant solutions on cyclic fatigue resistance of files directed us to conduct a thorough and comprehensive study to assess the effect of immersion in disinfectants on cyclic fatigue resistance of NiTi files, assuming that immersing the files in chemical disinfectants would change the cyclic fatigue resistance of files.

M3 Pro Gold (M3 Pro Gold, United Dental, Shanghai, China) and SP1 (V-Taper Gold; Shanghai, Fanta Dental, China) files are among the commonly used rotary files. SP1(V-Taper Gold) size F2 is a finishing file, made by H-wire technology and has a triangular cross section. The initial design of this file was done by the Endo Guidance technologies company (Dayton, Ohio, USA). The taper of this file is variable throughout the file. The reason for this design is to obtain the final form of the canal with greater preparation size in the apical third and to avoid excessive cutting of the canal walls in the coronal third. This file is suitable for a wide range of canal shapes.

The M3 Pro Gold is a recently presented NiTi instrument that was designed to be utilized in continuous rotation with a passive tip and a convex triangular cross-section. According to the manufacturer, M3 Pro Gold files are produced with a gold treated CM wire, which provides considerable flexibility and has higher cyclic fatigue resistance. The producer asserts that this instrument enables fast and safe preparation of root canals, particularly in curved root canals [14]. M3 Pro Gold files have a combination of martensite and austenite phases at room temperature. The current study aimed to assess the cyclic fatigue resistance of two above-mentioned nickel-titanium (NiTi) rotary files after immersion in 5% sodium hypochlorite (NaOCl) and Deconex.

MATERIALS AND METHODS

This study was approved by the ethic committee of Jundishapur University of Medical Sciences (IR.AJUMS.REC.1397.648 and IR.AJUMS.REC.1397.649). A total of 90 new M3 Pro Gold size 25.06 and SP1 size F2 files were chosen. Deconex (Deconex 53 Plus, Borer, Switzerland) and NaOCl (Cerkamed-Chloraxid 5%, Cerkamed, Poland) were also chosen as disinfectants. Forty-five files of the same brand were randomly assigned to three groups (n=15) and subjected to the following immersion protocol at room temperature for 5 minutes: no immersion (control group), immersion in 5% NaOCl, and immersion in Deconex. The files were then placed in a testing machine to assess the cyclic fatigue resistance of the files. To date, no specific international standard for testing cyclic fatigue resistance of NiTi files has been introduced, as a result of which several methods and devices have been presented to assess in vitro cyclic fatigue resistance of NiTi files. The device used in the current study consisted of a wooden base measuring 30×30cm which was fixed to the table to prevent vibration in the course of testing. A chromium-cobalt block with a stainless steel groove was attached to the base of the device by a screw. The stainless steel groove (artificial canal) corresponded to the size of a gutta-percha #25/06 with 45° curvature (Fig. 1).

Fig. 1: Designed device to measure the cyclic fatigue resistance of the files

A handpiece (ER64; NSK, Tokyo, Japan) was connected to the base by a rotary motor (DW11506-00-30; Aseptico, Woodinville, WA, USA), and a plastic fastening clip to the base so that when a file was attached to the handpiece, the cutting part of the file was placed completely in the stainless steel groove and was ready for testing. During the test, the handpiece rotated at 350rpm with 2N/cm torque for the SP1 and 3N/cm for the M3 Pro Gold files as recommended by the manufacturers. The handpiece fixative clamp was rotated in a transverse and vertical direction so that the files at the tip of the handpiece fit perfectly into the groove in the chromium-cobalt block without being subjected to any stress. After attaching each file to the handpiece, it started rotating at the recommended speed and torque for each file. While the files were rotating, the artificial canal (groove) was covered with a piece of tempered

Fig. 2: Tempered glass piece which was used to cover the groove

glass to prevent slipping of instrument (Fig. 2). In addition, the glass allowed the operator to observe the file while rotating. Oil spray (Hi-Clean, NSK, Tokyo, Japan) was used as a lubricant to reduce file friction in the artificial canal. All files were rotated until failure occurred. The fracture of the files was easy to detect as it was visible through the glass. The fracture time for each file was recorded using a timer. The number of cycles to fracture (NCF) was then determined by the following formula:

$$\boldsymbol{NCF} = \frac{time\ to\ failure\ (s) \times rotational\ speed}{60}$$

Statistical analysis:

To compare the cyclic fatigue resistance of SP1 and M3 NiTi rotary files based on the type of disinfectant solution, due to normal distribution of cyclic fatigue resistance data which was confirmed by the Kolmogorov-Smirnov test (P>0.05), and considering the equality of variances of cyclic fatigue resistance data in the study groups as confirmed by the Levene's test (P> 0.05), two-way ANOVA was applied to assess the effect of file type (NiTi rotary M3 file and SP1) and disinfectant solution (Deconex, sodium hypochlorite and control group) on cyclic fatigue resistance. Post-hoc LSD test was used for pairwise comparisons of cyclic fatigue resistance of the groups. P<0.05 was considered significant.

RESULTS

Cyclic fatigue resistance of SP1 and M3 NiTi rotary files based on the type of disinfectant are reported in Table 1.

Table 1. Cyclic fatigue resistance of NiTi rotary files based on the applied disinfectants

Files	Deconex		5% NaOCl		No immersion		Total	
	N	Mean±SD	N	Mean±SD	N	Mean±SD	N	Mean±SD
M3	15	79.67±8.2	15	72.93±6.92	15	111.6± 7.02	45	88.07±18.53
SP1	15	158.53±8.14	15	120.67±19.71	15	118±19.08	45	132.4±23.46
Total	30	119.1±40.9	30	96.8±28.28	30	114.8±10.82	90	110.23±30.63

SD: standard deviation

Based on the results of our statistical analyses the effect of file type was significant (P<0.001), which indicates a significant difference between the cyclic fatigue resistance of M3 and SP1 files immersed in disinfectants. Cyclic fatigue resistance of SP1 files regardless of type of disinfectant was significantly greater than M3 (P<0.001). The effect of type of disinfectant was also significant. There was a significant difference between the effect of Deconex, sodium hypochlorite and control group on cyclic fatigue resistance of the files (P<0.001). The results of post hoc LSD test showed that the cyclic fatigue resistance of the control group and the files immersed in Deconex were significantly higher than those immersed in sodium hypochlorite (P<0.001).

No significant difference was found between the effect of Deconex and control group on cyclic fatigue resistance of the files (P=0.151). The interaction effect of file type and disinfectant was also significant (P<0.001). Considering the significance of the interaction effect of file type and disinfectant, to compare the effect of each disinfectant on cyclic fatigue resistance of each file type, the post hoc LSD test was used.

The results showed that the cyclic fatigue resistance of M3 files in the control group was significantly higher than those immersed in Deconex and sodium hypochlorite (P<0.001). Also, the cyclic fatigue resistance of M3 files immersed in Deconex was significantly higher than the files immersed in sodium hypochlorite (P=0.017). The cyclic fatigue resistance of SP1 immersed in Deconex was significantly higher than the control group and SP1 files immersed in sodium hypochlorite (P<0.001). No significant difference was found between the cyclic fatigue resistance of the control group and SP1 files immersed in sodium hypochlorite (P=0.616; Fig. 3).

DISCUSSION

A number of factors affect the cyclic fatigue resistance of NiTi rotary files. The cyclic fatigue resistance of the files affects the outcome of instrumentation particularly in curved canals. Most studies [12-16] on cyclic fatigue resistance of NiTi files emphasis on features such as design or alloy composition of the files; therefore, in present study, we aimed to explore the effect of immersion in chemical disinfectants on cyclic fatigue resistance of NiTi rotary files. The effects of disinfectants such as NaOCl on cyclic fatigue of NiTi files have already been studied to some extent and studies have reported conflicting results [8,16]. To date, no study has assessed the effect of immersion in NaOCl and Deconex disinfectants on cyclic fatigue resistance of M3 Pro Gold and SP1 files.

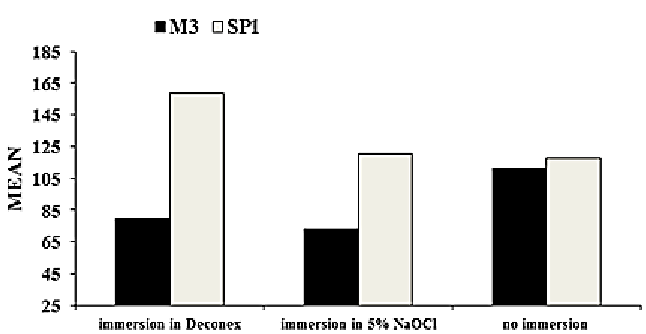

Fig. 3: Mean fatigue resistance of SP1 and M3 NiTi rotary files based on the type of disinfectant

Thus, we designed the current study to address this topic. Immersion of SP1 files in Deconex significantly increased the cyclic fatigue resistance of the files. However, immersion of M3 Pro Gold files in the NaOCl significantly reduced the cyclic fatigue resistance of the files. Pedulla et al, performed a study to assess the cyclic fatigue resistance of Revo S SU, Mtwo, and Twisted File after immersion in NaOCl under conditions similar to clinical conditions.

Pedulla et al. [8] concluded that static or dynamic immersion of files in NaOCl for 1 or 5 minutes did not significantly decrease the cyclic fatigue of the files. However, they found that the file type affected cyclic fatigue, as the cyclic fatigue of Twisted Files was greater than Mtwo, and the cyclic fatigue of Revo S SU files was the lowest. The result of our study was in agreement with the afore-mentioned study in which the file brand had an impact on cyclic fatigue. To be more specific, in our study, the immersion of the M3 files in NaOCl significantly decreased the cyclic fatigue resistance of the files, while immersing the SP1files in the same solution did not have a significant effect on their cyclic fatigue resistance. One explanation for the difference in the results of the two studies might be the use of different types of testing devices and their inherent limitations [14]. One limitation of the testing device is that the file is loose in the groove that serves as an artificial canal (which was made of stainless steel in our study and several other studies [8,9] . The groove (artificial canal) should be wide enough to accommodate files with different diameters and tapers, allowing this artificial environment to have adequate apical flexibility at the curvature. Such artificial conditions do not well simulate the clinical condition of the canal when small files are used because torsional forces along the file may have a greater effect on cyclic fatigue [15]. In addition, the radius of curvature of the artificial canal affects the test results, because the smaller the radius of curvature of the artificial canal, the less the cyclic fatigue resistance would be. The radius of curvature in our study was 5 mm; perhaps if the radius of curvature was more or less, different results would have been obtained [16]. It is noteworthy that the conditions of the artificial canal are considerably different from the actual root canals. For instance, if the files in our study had been inserted in canals with severe curvature or calcified canals rather than being tested in the artificial canal, the dentin resistance against the flute of the files would be higher, and the files would experience a higher level of torque, and when the torque is higher than the file's elastic limit, fracture occurs. In other words, in actual canals, fractures might occur earlier than artificial canals due to different canal conditions [17].

An additional argument to note about the artificial canal is that our experiment was done at room temperature (25°C) (which varies in different geographical locations), while the files rotate at intracanal temperature (31-35°C) in the clinical setting [18-20], which is different from room temperature, since the ambient temperature at which the file rotates affects the cyclic fatigue resistance of the file. Different results may be obtained if testing is repeated at intracanal temperature [21].

In the current study, the cyclic fatigue resistance of the files immersed in Deconex was found to be higher than that of files immersed in NaOCl. NiTi files are susceptible to corrosion in certain media that contain chlorine; corroded files consequently lead to reduction of cyclic fatigue resistance [22]. In fact, corrosion occurs by removal of nickel from the surface of the file, which causes micro-pitting. It is assumed that micro-structural defects can create areas where stress accumulates, leading to crack formation and weakening of the file structure [23]. Moreover, the maximum stress is created at the center of the simulated curve; thus, if the corrosive zone is present at that level, the file may break earlier. However, if the corrosive attack reaches the file in a region other than the point of maximum stress concentration caused by the testing device, it would not probably decrease the cyclic fatigue resistance of the file [8]. In other words, where corrosion occurs in the file affects the test result. In the present study, the immersion protocol and testing device were the same for both file types; therefore, the difference in the results between the two file types must be related to other factors.

As mentioned earlier, in the current investigation, the effect of file type on cyclic fatigue resistance was significant; the cause can be attributed to different characteristics of M3 and SP1 files. The difference in the cross-sectional design of the respective files is one such factor; however, the effect of cross-sectional design on cyclic fatigue resistance of files is controversial, as some studies claimed that the cross-sectional design of the files had no effect on their cyclic fatigue resistance [24-26], some others showed that files with square-shaped cross-section had higher cyclic fatigue resistance [27], while others demonstrated that files with triangular cross-section had greater cyclic fatigue than those with square-shaped cross sections because they had a lower metal mass [28].

Another factor that could be the reason for the diverse effects of chemical disinfectant solutions on cyclic fatigue of M3 Pro Gold and SP1 files is the quality of these files, as NiTi is a very sensitive alloy to thermal and mechanical stress, which can occur during raw material processing or during endodontic file processing. Transition temperature control is important to ensure optimal super-elastic properties, and any machining process affects the transition temperatures, which is why the quality of the file affects cyclic fatigue. Peters et al. [29] assessed the impact of immersion in NaOCl for 1 and 2 hours at 21°C and 60°C on cyclic fatigue resistance of size 25.04 Profile and RaCe files and found that cyclic fatigue resistance of the files immersed in NaOCl at 60°C was lower than that of files immersed in NaOCl at 21°C, and it was advocated that NiTi rotary files should be considered as disposable files.

The results of the present study demonstrated a significant difference between the effect of two types of disinfectant solutions on cyclic fatigue resistance of the files; the cause can be related to the difference between the composition, pH, temperature, and concentration of disinfecting solutions. It should be noted that some other properties of the files have impact on cyclic fatigue resistance of files. The difference between the results of M3 Pro Gold and SP1 files might also be related to the different composition of the two files since file composition is not disclosed precisely by the manufacturers [30]. The difference in the flute design of M3 Pro Gold and SP1 may be another reason for the different results.

Berutti et al. [31] investigated the effect of NaOCl on NiTi alloys by immersing ProTaper files in 5% NaOCl at 50°C for 5 minutes, and found that immersion in NaOCl negatively impacted the files cyclic fatigue, mainly when the files were completely immersed in the solution, since different composition of working part and shaft would cause galvanic corrosion. It should be kept in mind that in the present study, there was a number of confounding factors which could have affected the results. For example, the smaller the file size and diameter, the greater the cyclic fatigue would be, and this might have affected not only our study results, but also others' results [13,21,32]. In addition, we used new files in the present study, although we did not use a microscope to ensure no defect on the file surfaces prior to the test, as during machining operation very small scratches and grooves may form on the surface of some files by the cutting tool action and such surface defects might affect the cyclic fatigue of the files [33]. In total, the effect of immersion in NaOCl and Deconex on cyclic fatigue of M3 Pro Gold and SP1 V-Taper files was variable; NaOCl diminished the cyclic fatigue of M3 Pro Gold files while immersion in Deconex augmented the cyclic fatigue of SP1 files.

CONCLUSION

In conclusion based on the results obtained in the current investigation, the effect of immersion in disinfectants on cyclic fatigue resistance of NiTi instruments is determined by the type of file and disinfectant.

CONFLICT OF INTEREST STATEMENT

None declared.

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